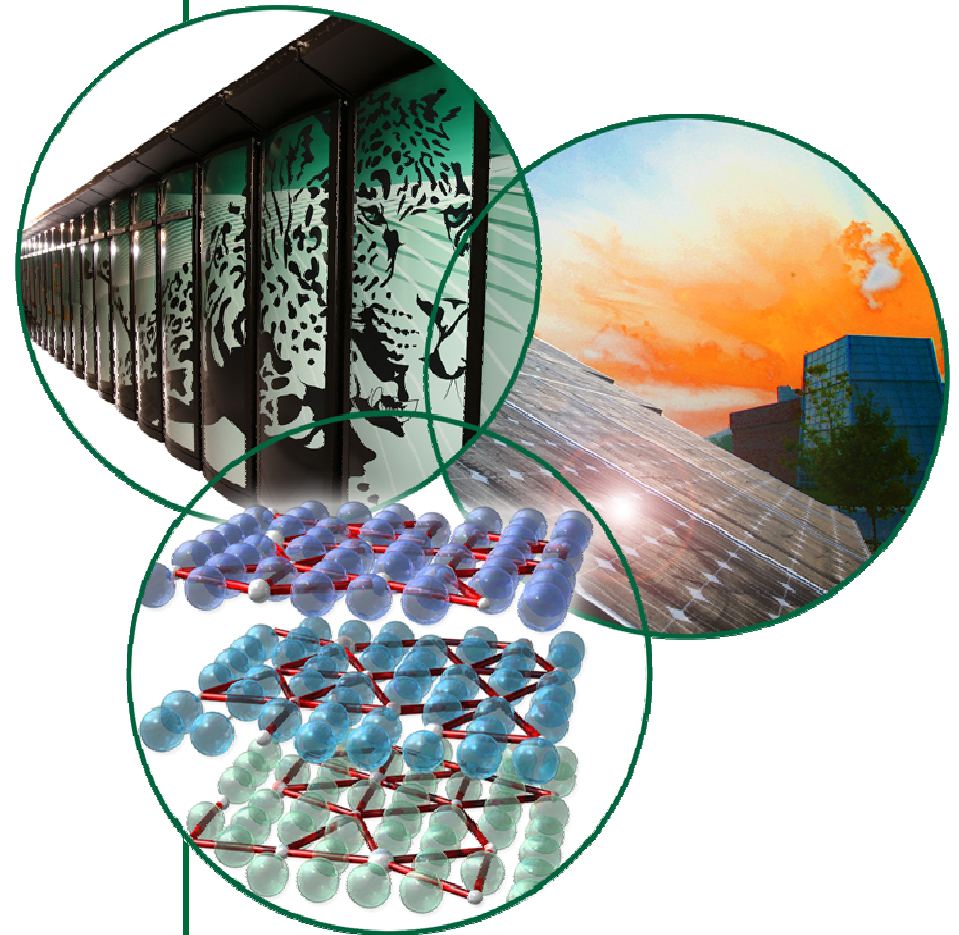


SNS (Linac) Experience

ESS-Bilbao Initiative Workshop

March 16-18, 2009

J. Galambos on behalf of the
SNS Team



SNS: Started as a Greenfield Site



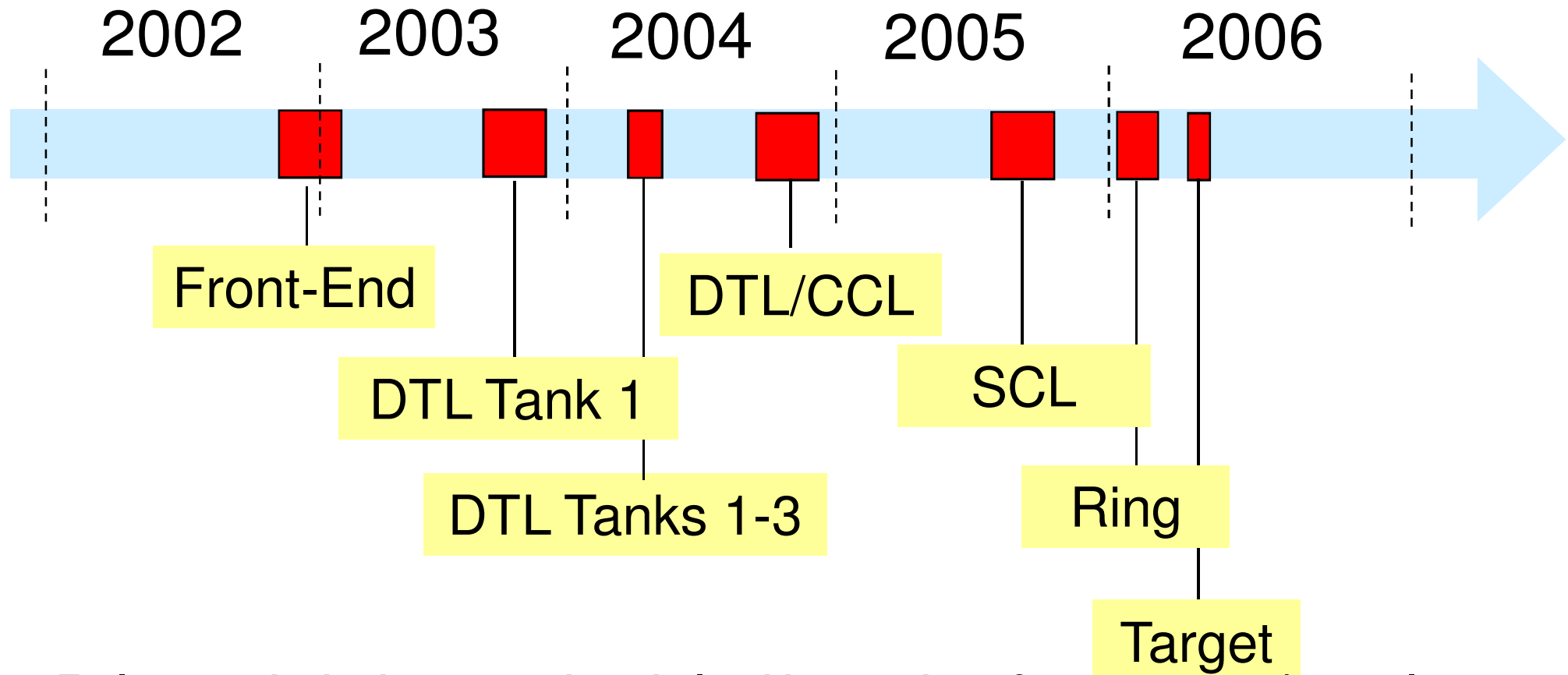
The SNS Partnership Experience



ORNL was responsible for integration, installation, commissioning and operation

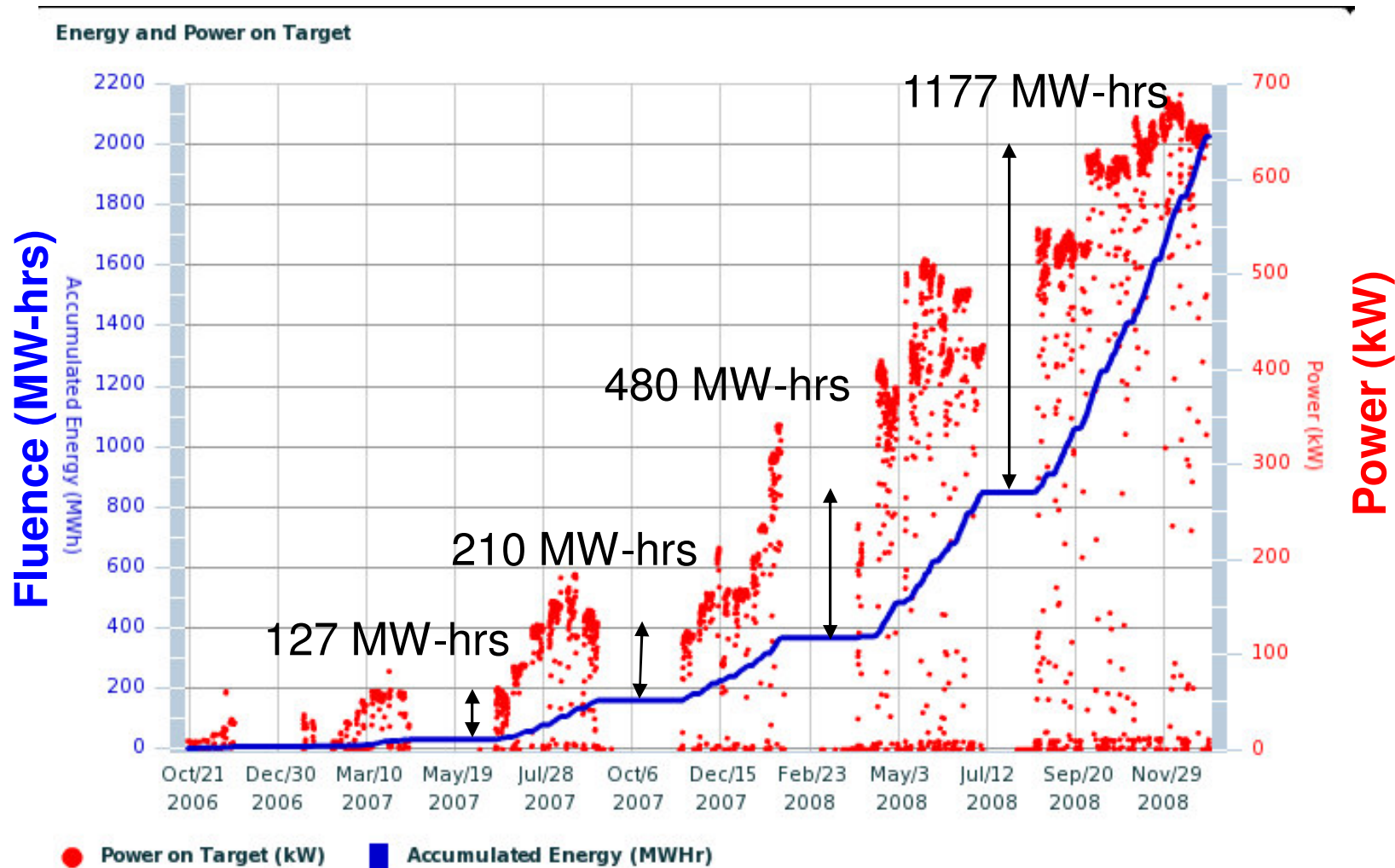
Need a strong central team to take intellectual ownership of the accelerator

Commissioning Timeline – Start as Early as Possible



- Early commissioning campaigns helped integration of new systems (controls, timing, diagnostics, software applications, ...)
- Less time was available for latter stages than originally planned

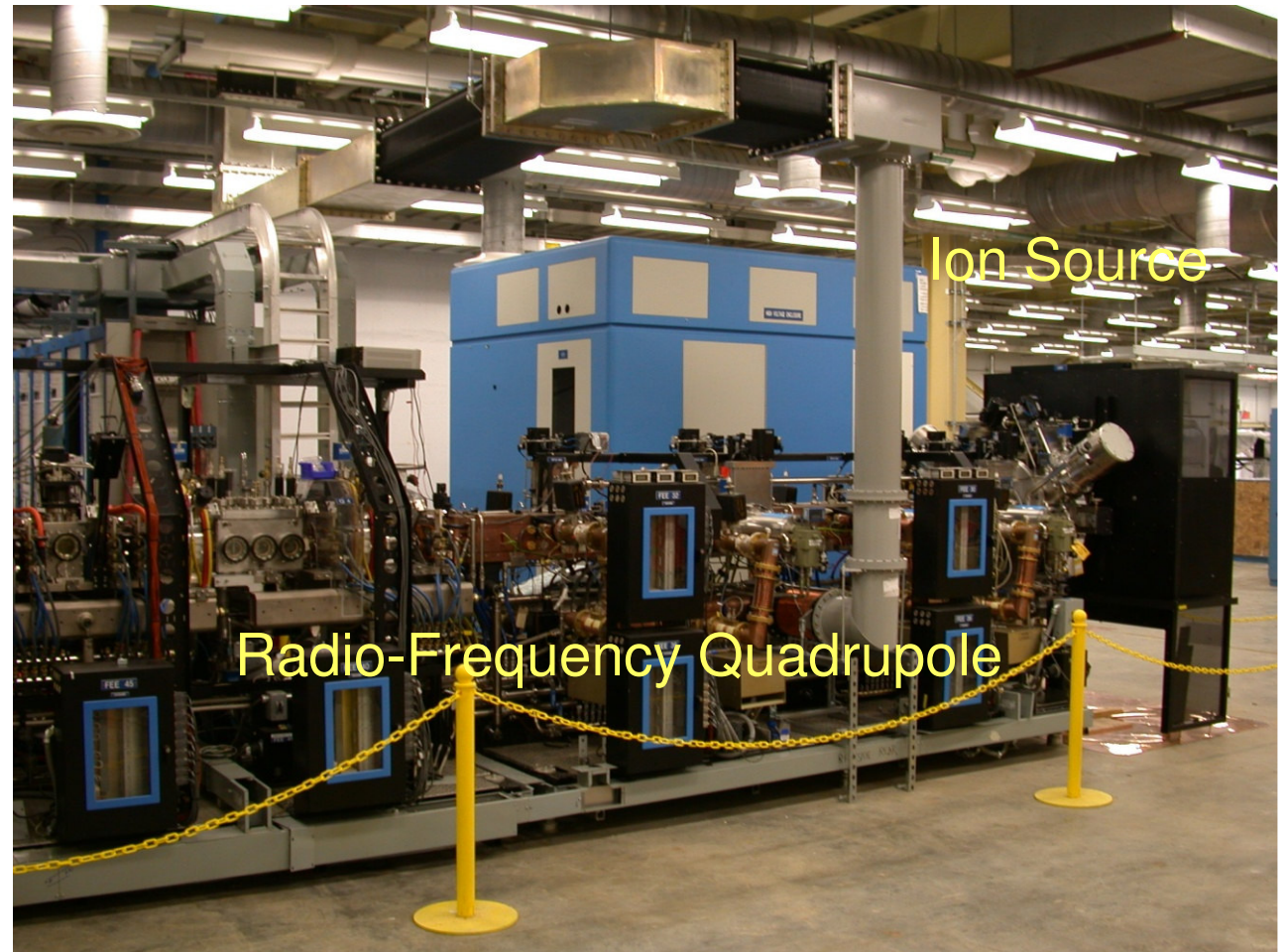
Rapid Increase in Power and Fluence



- Doubling the integrated power delivered to the Target, over the last several run-cycles

RFAQ

- 3.5 m
- 2.5 MeV output
- 402.5 MHz



- 2 frequency “detuning” incidents
- Duty factor operated at $\sim 4\%$, need to get 6%
 - (working on this now)

Drift Tube Linac

- 37 m
- 87 MeV output
- 6 Tanks
- 210 drift tubes
- PM quadrupoles
- 2.5 MW klystrons (402.5 MHz), 1 per tank



- *Experience with PM quadrupoles is fine*
- *Minimal beam loss / activation observed*
- *Robust structure*

Coupled Cavity Linac

- 55 m
- 186 MeV output
- 4 modules
- 48 segments
- 5 MW klystrons (805 MHz), 1 per module



CCL is also a robust structure

- Issues with RF induced gate-valve failures

Some beam loss near the CCL entrance and exit

Superconducting Linac

- SCL accelerates beam from 186 to 1000 MeV
- SCL consists of 81 cavities in 23 cryomodules
- Two cavities geometries are used to cover broad range in particle velocities
- Operate at 2.1 K
- 81 klystrons (805 MHz, 500 kW)



Medium beta – 0.61

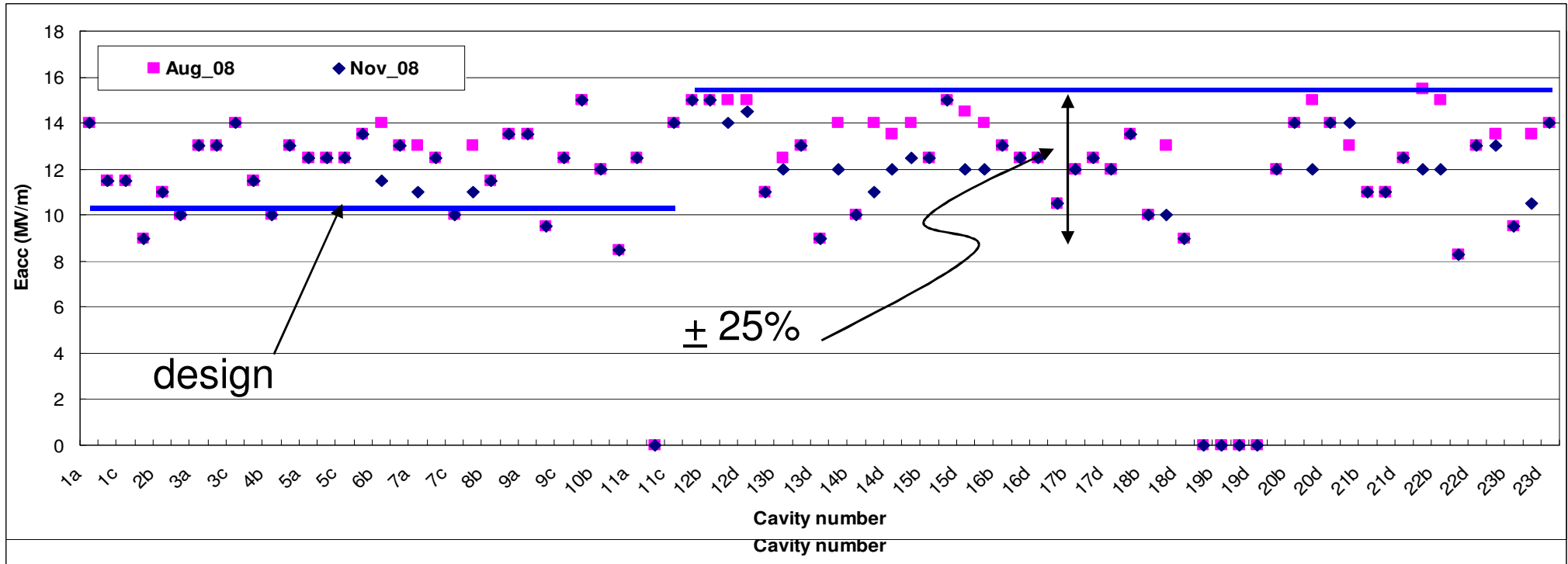


High beta – 0.81



- *SCL is flexible*
- *Issues with accessories (HOM couplers, piezo tuners, ...)*
- *Unexpected low level of beam loss*

SCL Gradients – large scatter

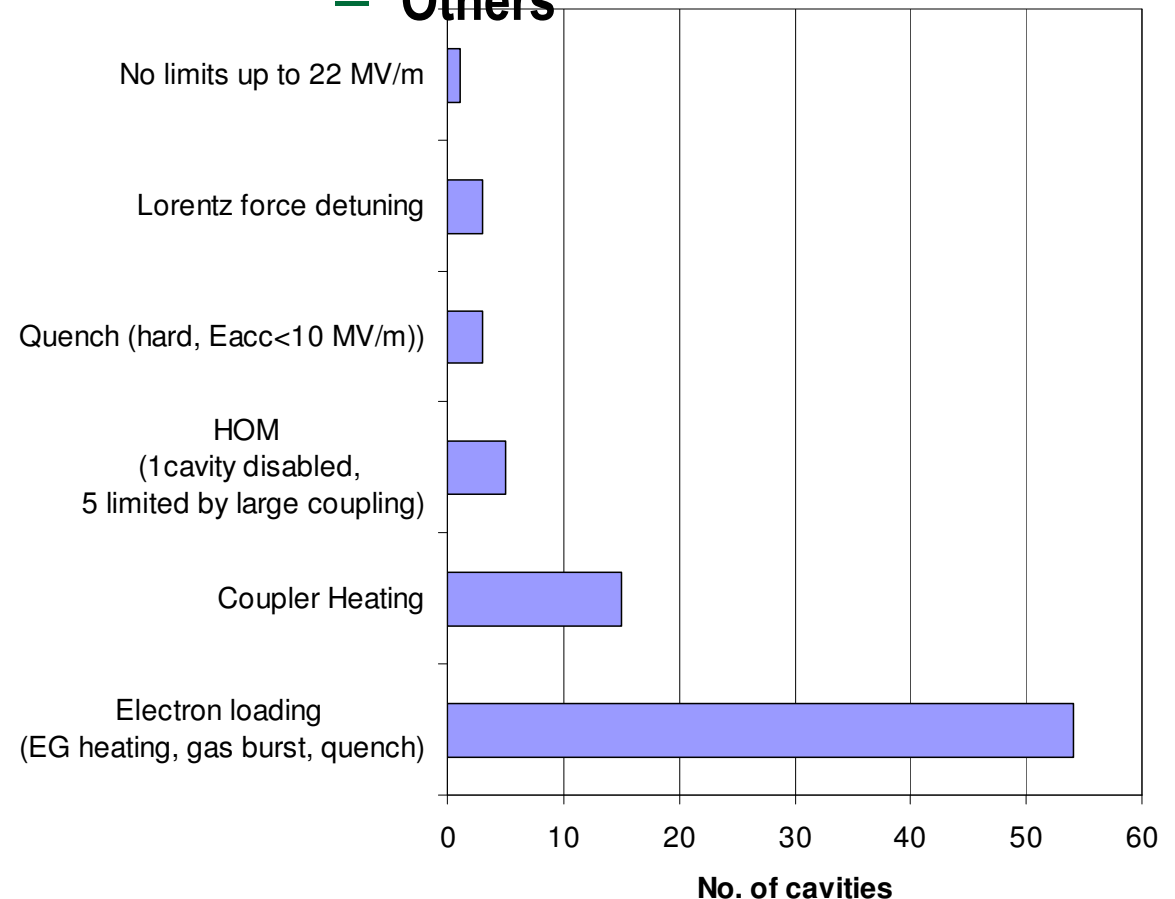
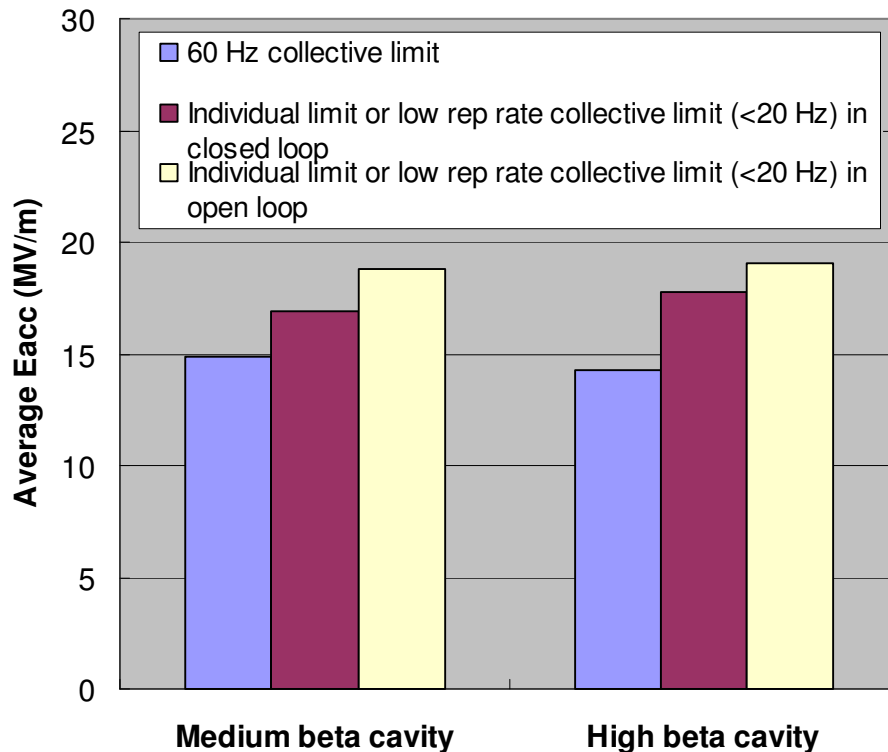


- Cavity gradients settings are not uniform nor constant
- Relative to design, the medium β cavities over-perform, high β cavities underperform
- Overall we have $\sim 7\%$ less energy gain than design
- Need tools to allow flexible setup (840 – 1010 MeV)

Linac Energy Limiting factor (I)

- Collective limits require operating cavities 20-25% below the “ideal” individual limits
- We are starting a plasma processing campaign to increase operational gradients

- Cavity performance limits
 - Field emission (major limiting factor)
 - Coupler heating
 - Others



Linac RF Layout

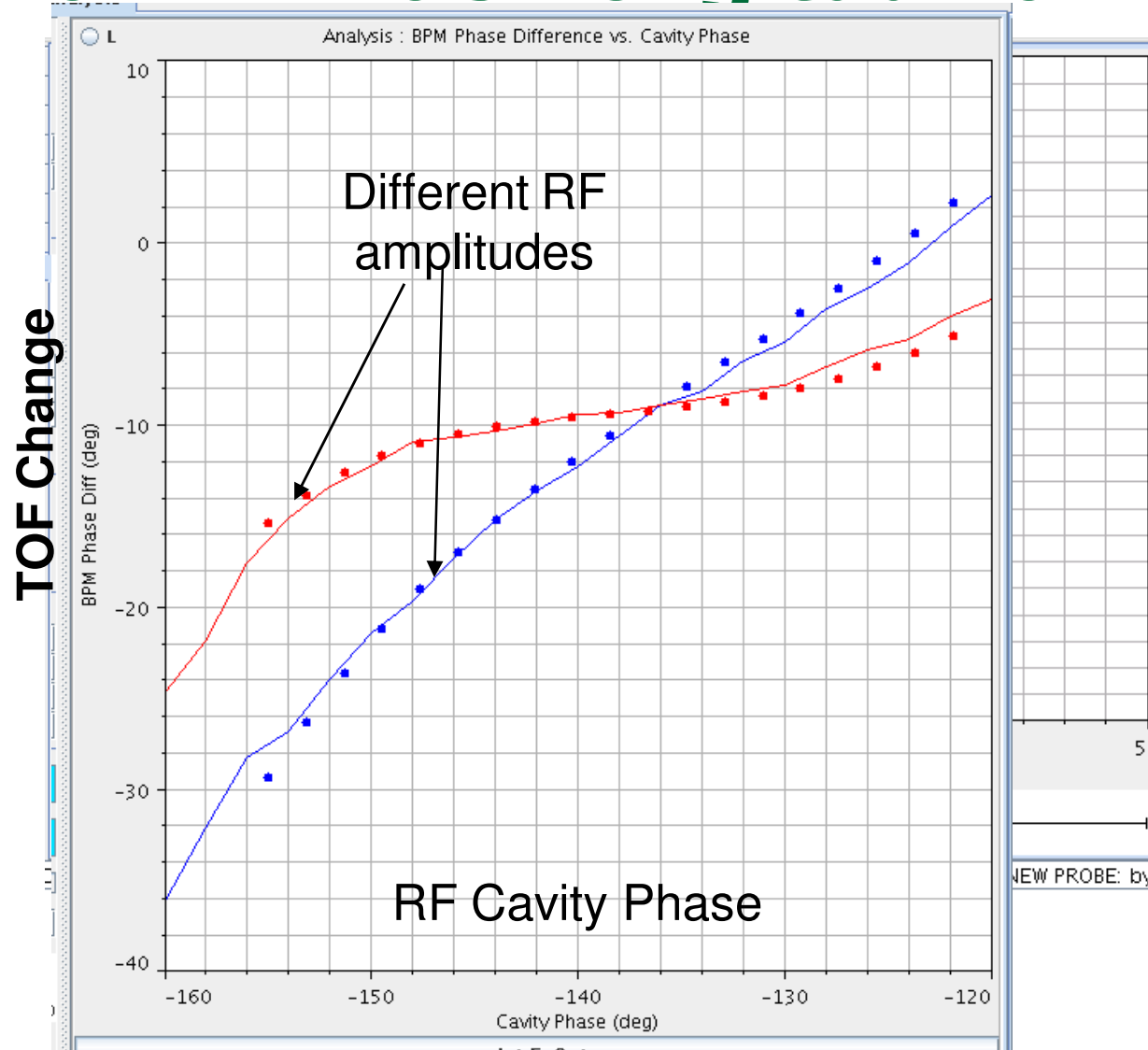
402.5 MHz, 2.5 MW klystron



- Warm linac has 10 independently powered cavities
- SCL has 81 independently powered cavities
 - Many values to set w.r.t. the beam
 - A lot of Equipment to keep running!!!

(81 total powered)

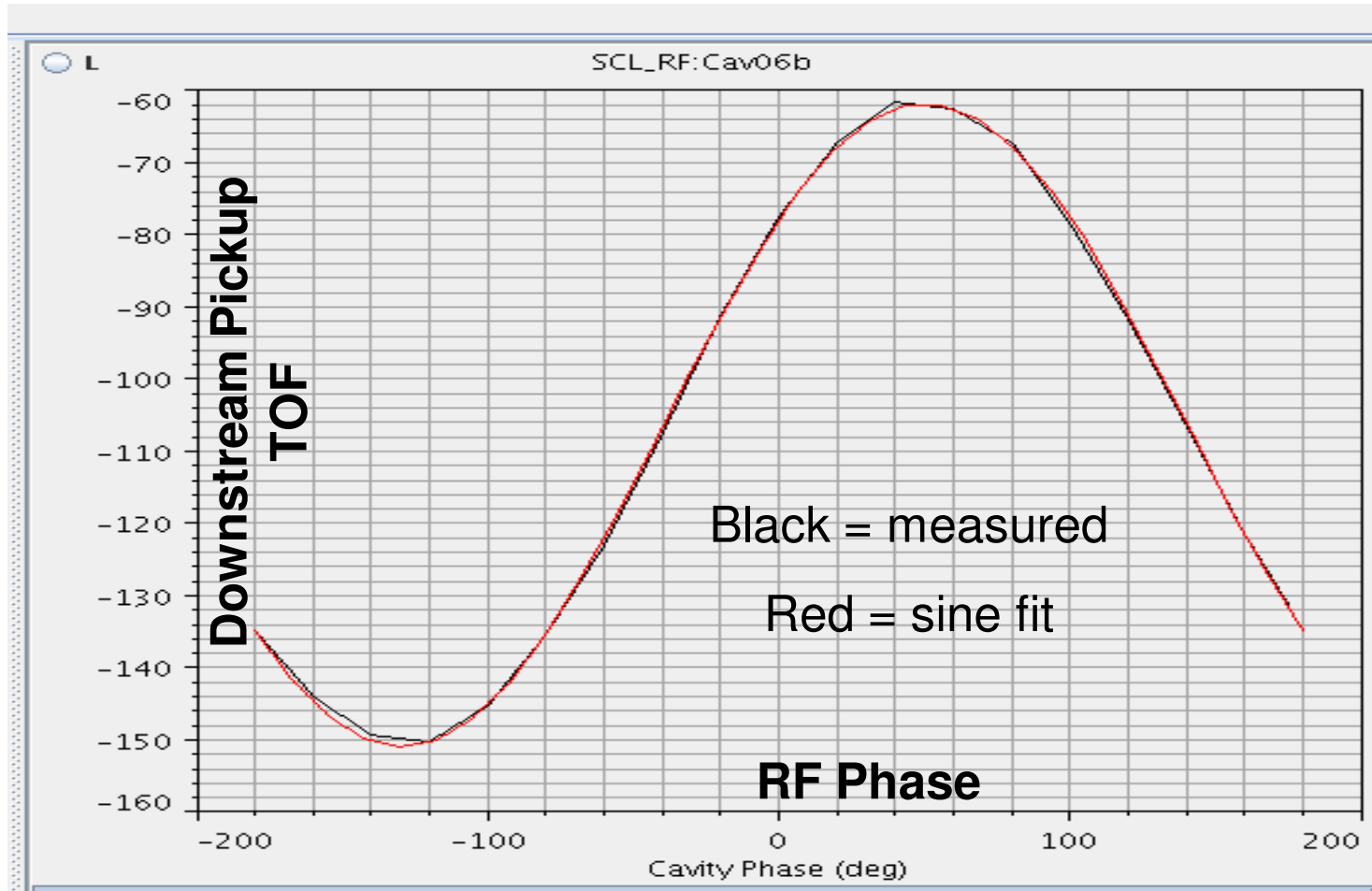
Warm Linac Longitudinal Beam Setup



- Each cavity has a unique response (signature) to phase and amplitude scans
- Phase scan signature matching method uses model to match measurements and determine RF amplitude and phase setpoints

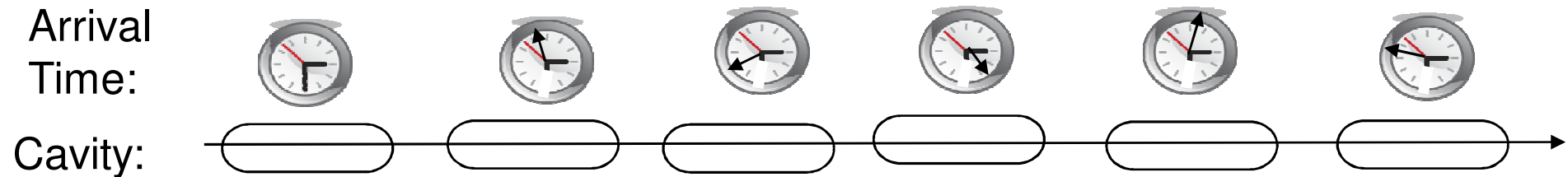
- Large phase advance (longitudinal) and energy gain per accelerating structure
- Single correct RF phase and amplitude setting

SCL Longitudinal Beam Setup



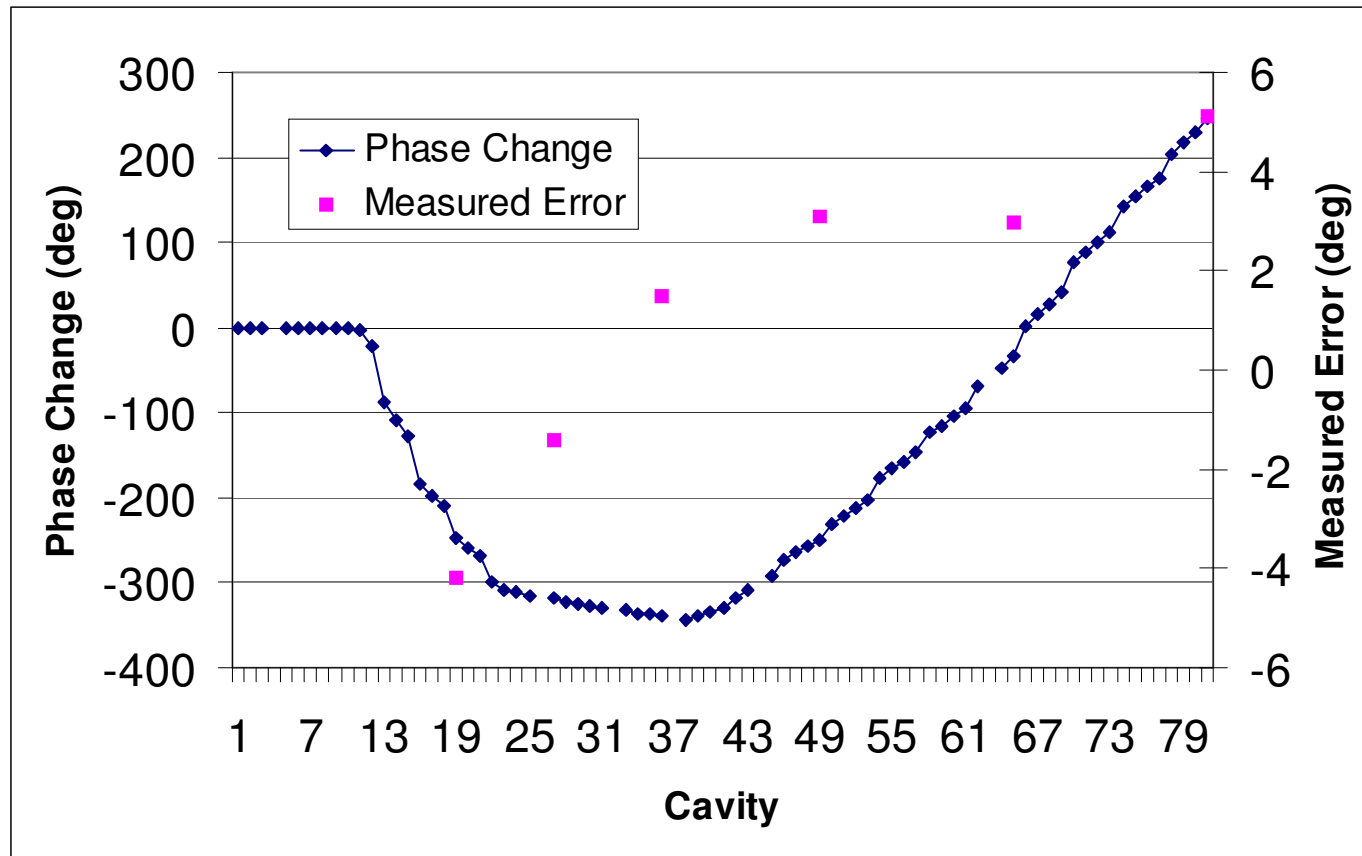
- Small $\delta\beta$ and small longitudinal phase advance per cavity
 - Close to ideal RF gap kick – easy to understand the RF relationship with the beam
- No absolute correct setting for each cavity!
 - Set each cavity amplitude for the maximum safe gradient
 - Flexibility in the RF phase setup

Superconducting Linac RF Setup



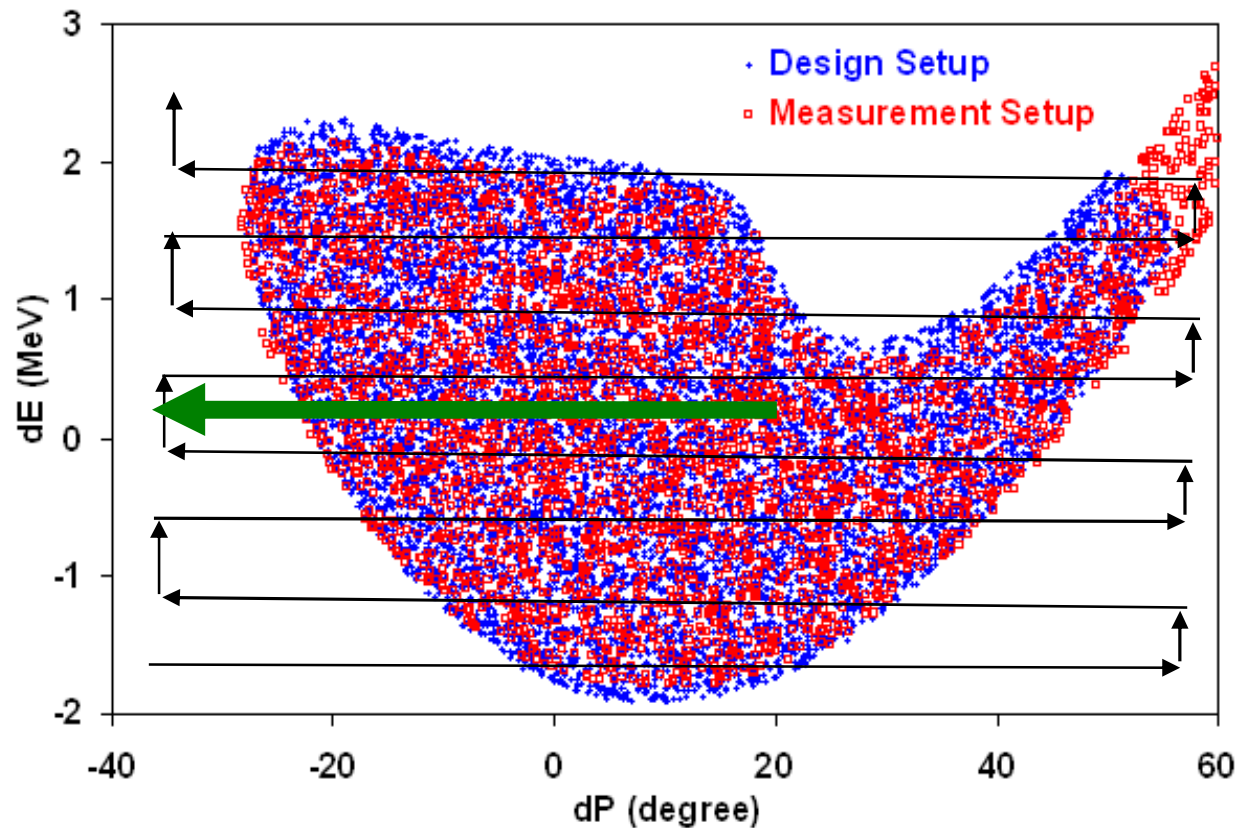
- **Model based predictions of the change in the downstream RF setup based on changes in upstream RF amplitude and/or phases are possible**
 - Use the change in predicted arrival time
 - Quickly recover from upstream RF changes
- **Introduces many possibilities**
 - The SCL can be viewed as a collection of infinitely programmable RF kicks

Application of the Cavity Fault Recovery Scheme (I)



- In the spring 2006, 11 cavities had to be either turned off or have their amplitudes reduced for safe operation, 1 cavity was returned to operation
- The fault recovery scheme was applied “all at once”
- Phase scan spot checks indicate the scaling was within 4 degrees
- No detectable change in beam loss

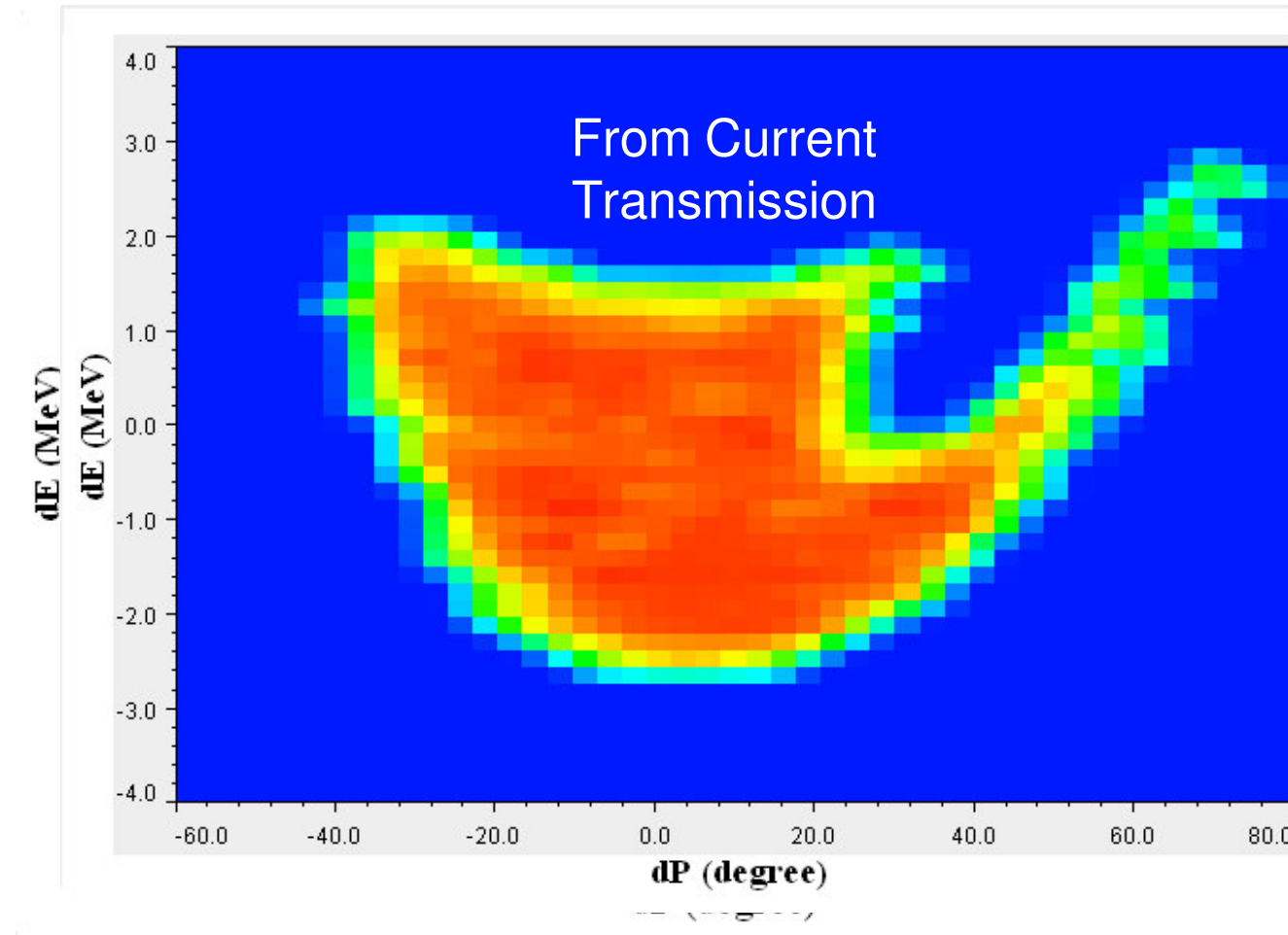
SCL Acceptance Measurement (Y. Zhang)



**Consider this
part of the scan**

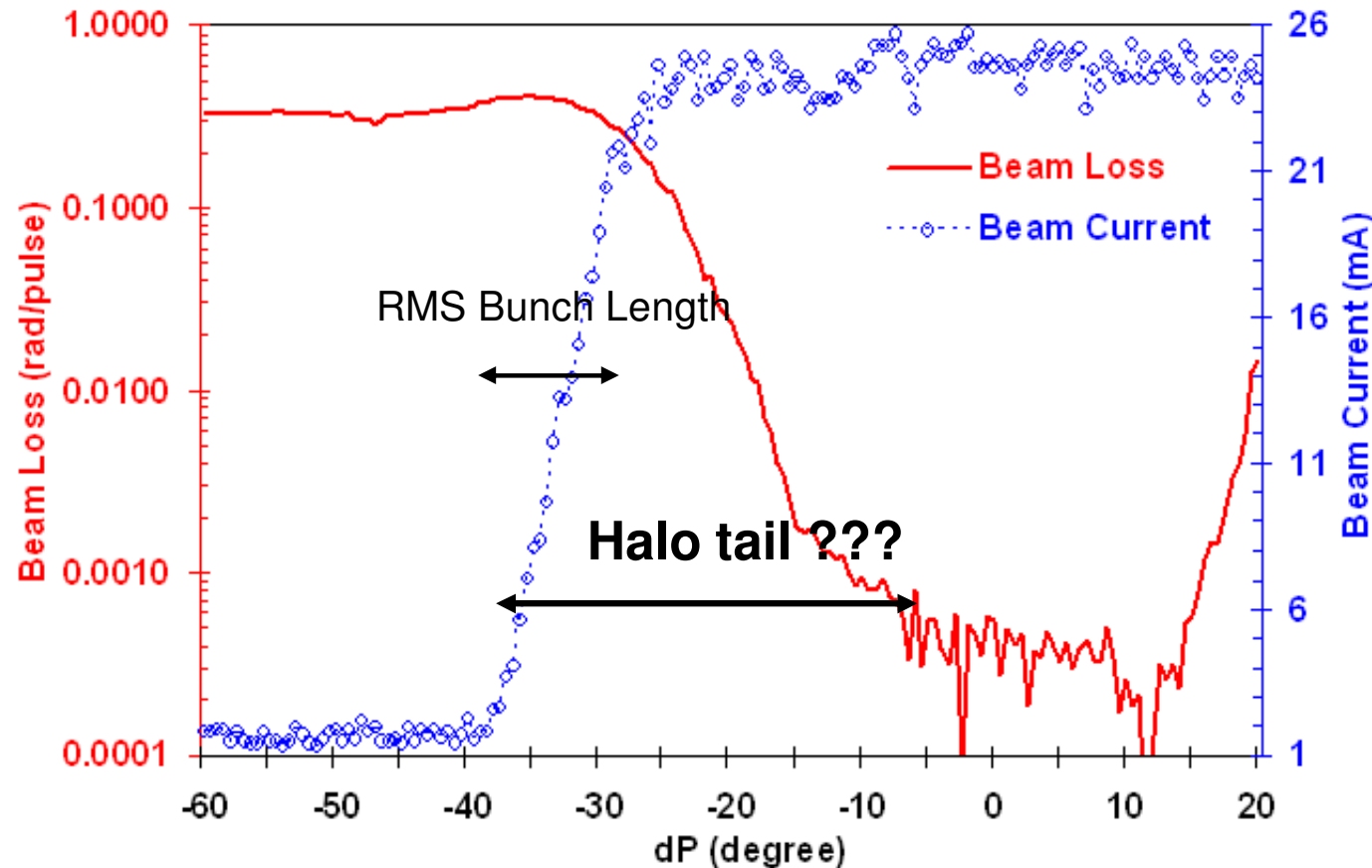
- Can calculate the longitudinal acceptance space for the SCL linac
- Using scaling techniques one can perform scans across the phase space and measure transmission

Measured SCL Acceptance



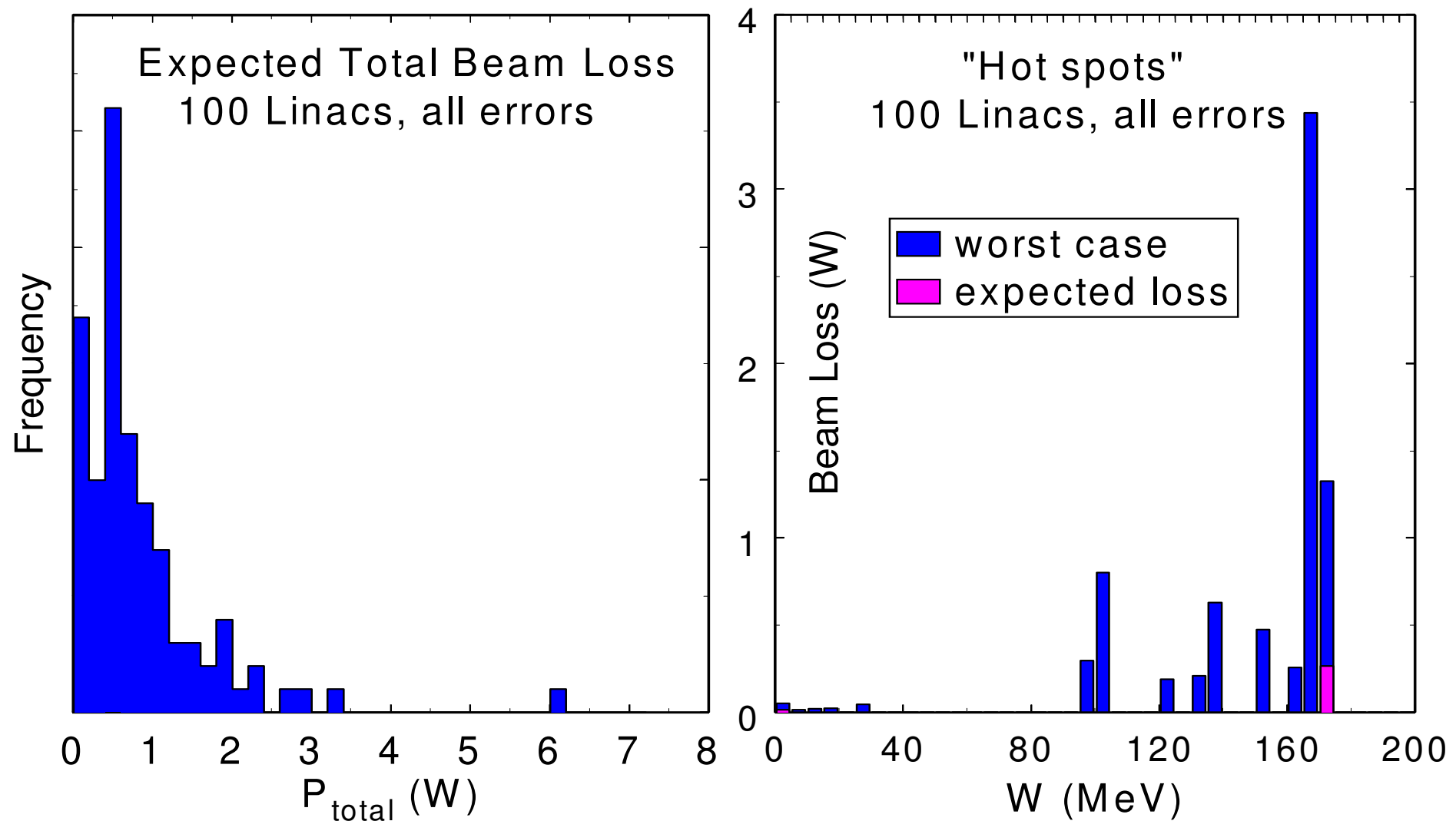
- Create an acceptance measurement from the scans

A Closer Look at a Phase Scan (courtesy Y. Zhang)

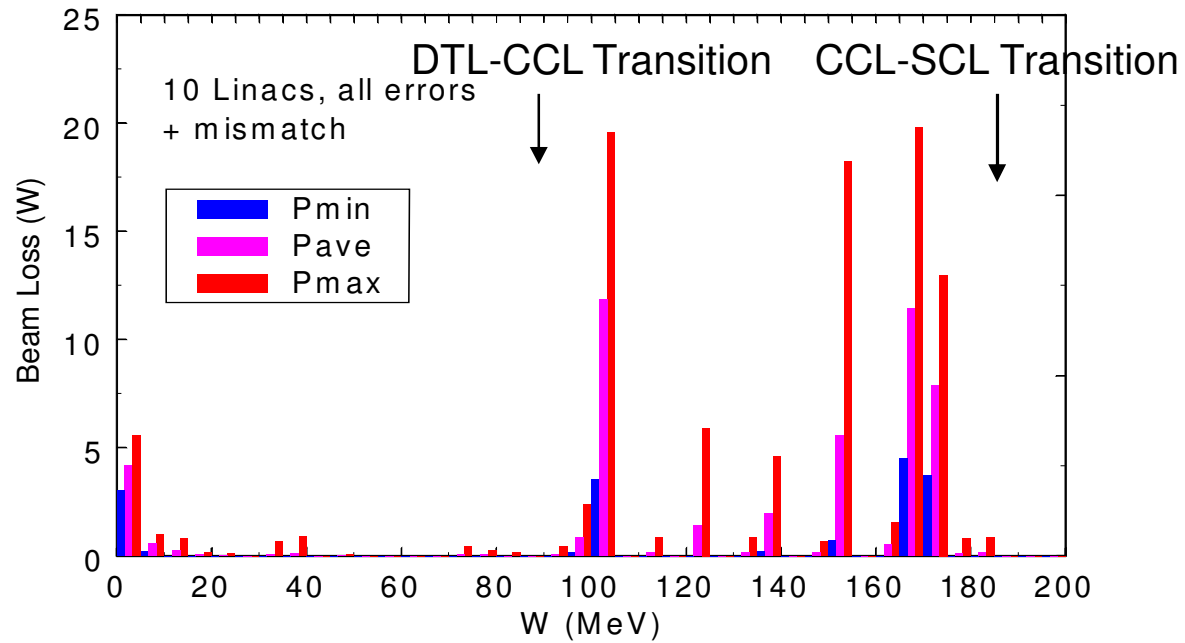


- Scan the beam phase for a constant input beam energy
 - Measure the transmitted beam current (core beam)
 - Measure the Beam Loss (halo indicator)

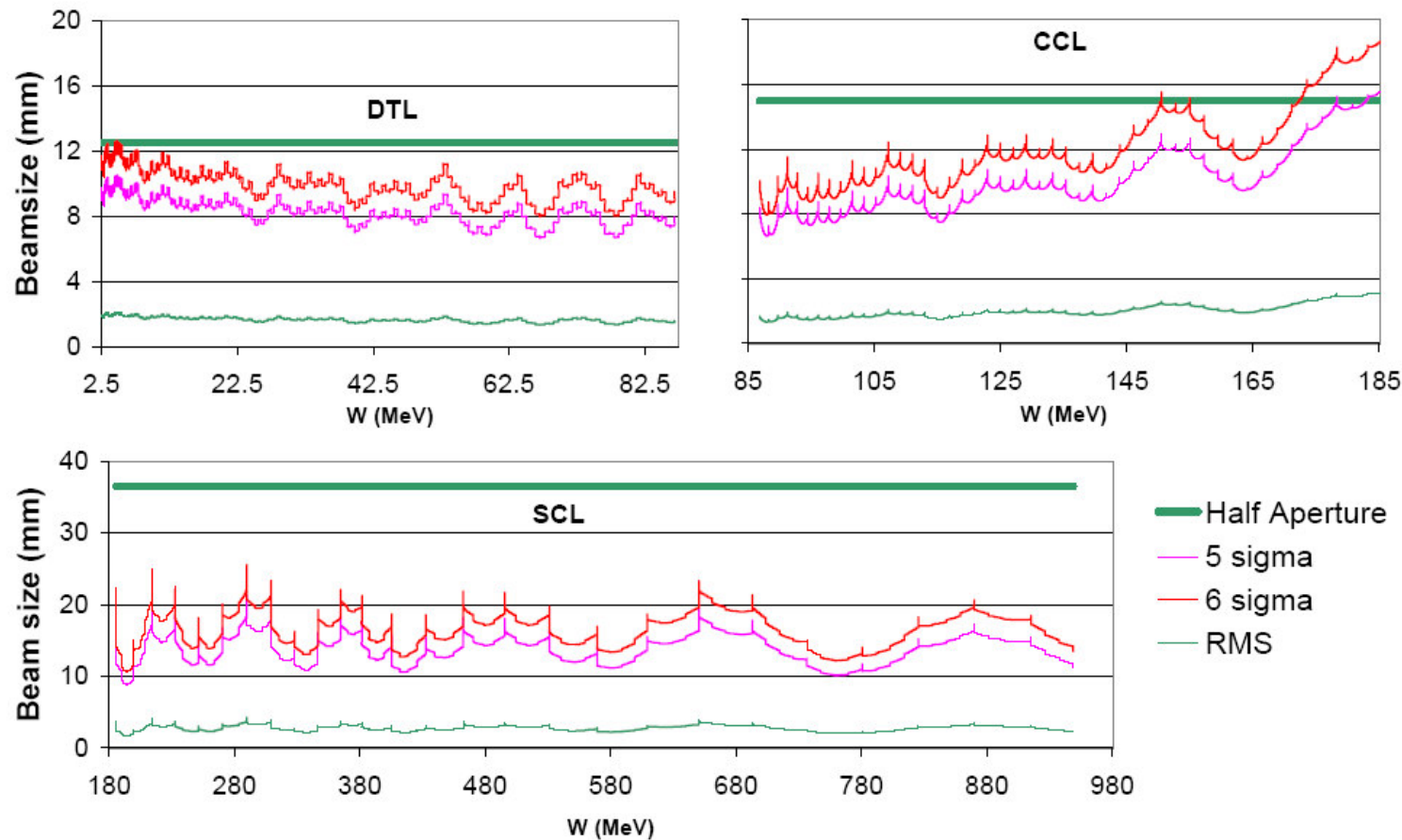
Total Expected Beam Loss & Hottest Expected Spot Meet Requirement



Linac Beamloss Study



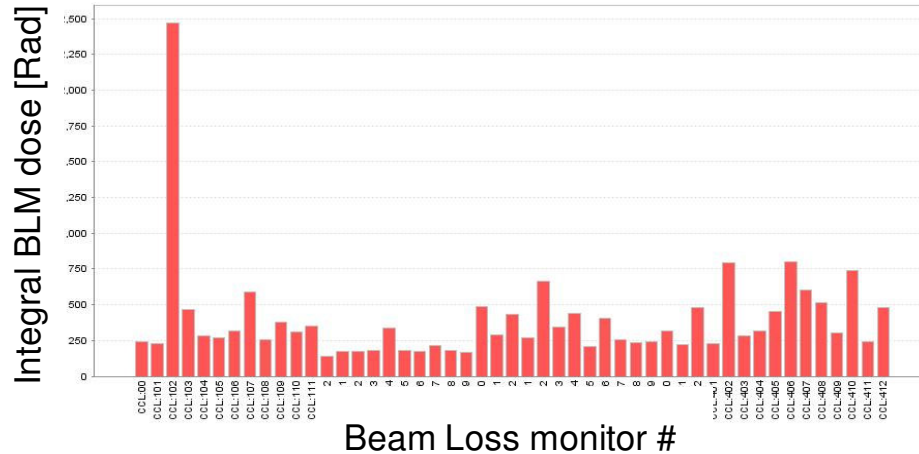
Linac Beam Loss Predictions



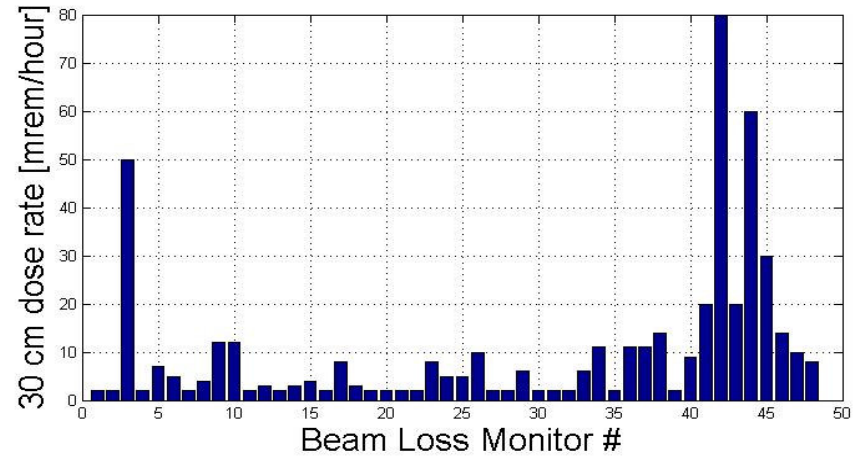
- Some beam loss possible in DTL / CCL
- No beam loss predicted in the SCL

CCL losses and activation

Prompt radiation due to beam loss



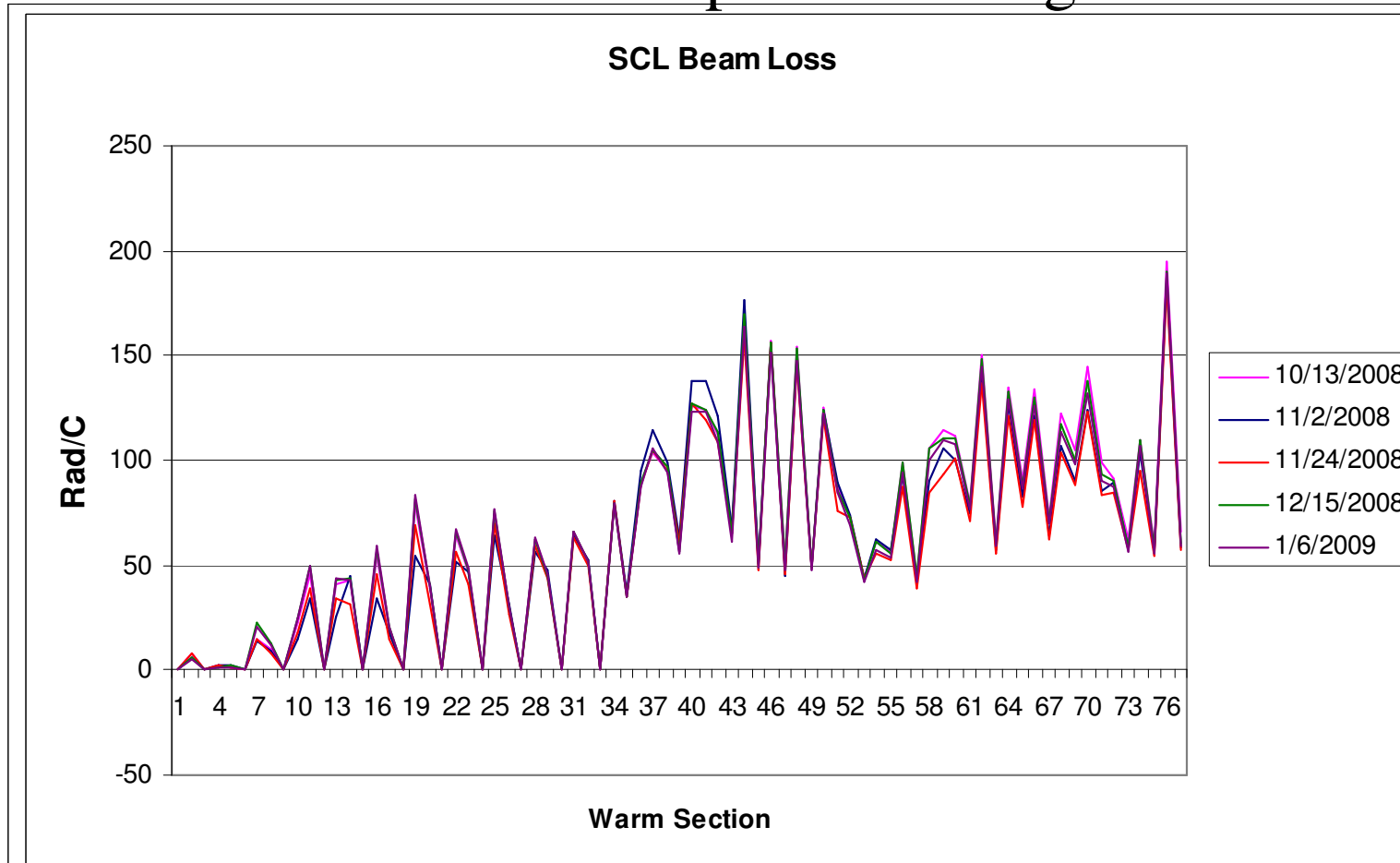
Residual activation @ 1ft after ~ 48h



- Two major loss sources
 - Longitudinal at DTL/CCL transition
 - Transverse at the CCL end
 - Hot spot at CCL406 is very unusual. Stripping on residual gas is suspected
- Mitigation measures
 - Stronger longitudinal focusing in MEBT (will install new RF amplifiers)
 - Additional dipole correctors in CCL (under consideration)
 - Modified transverse optics in CCL4 (under study)

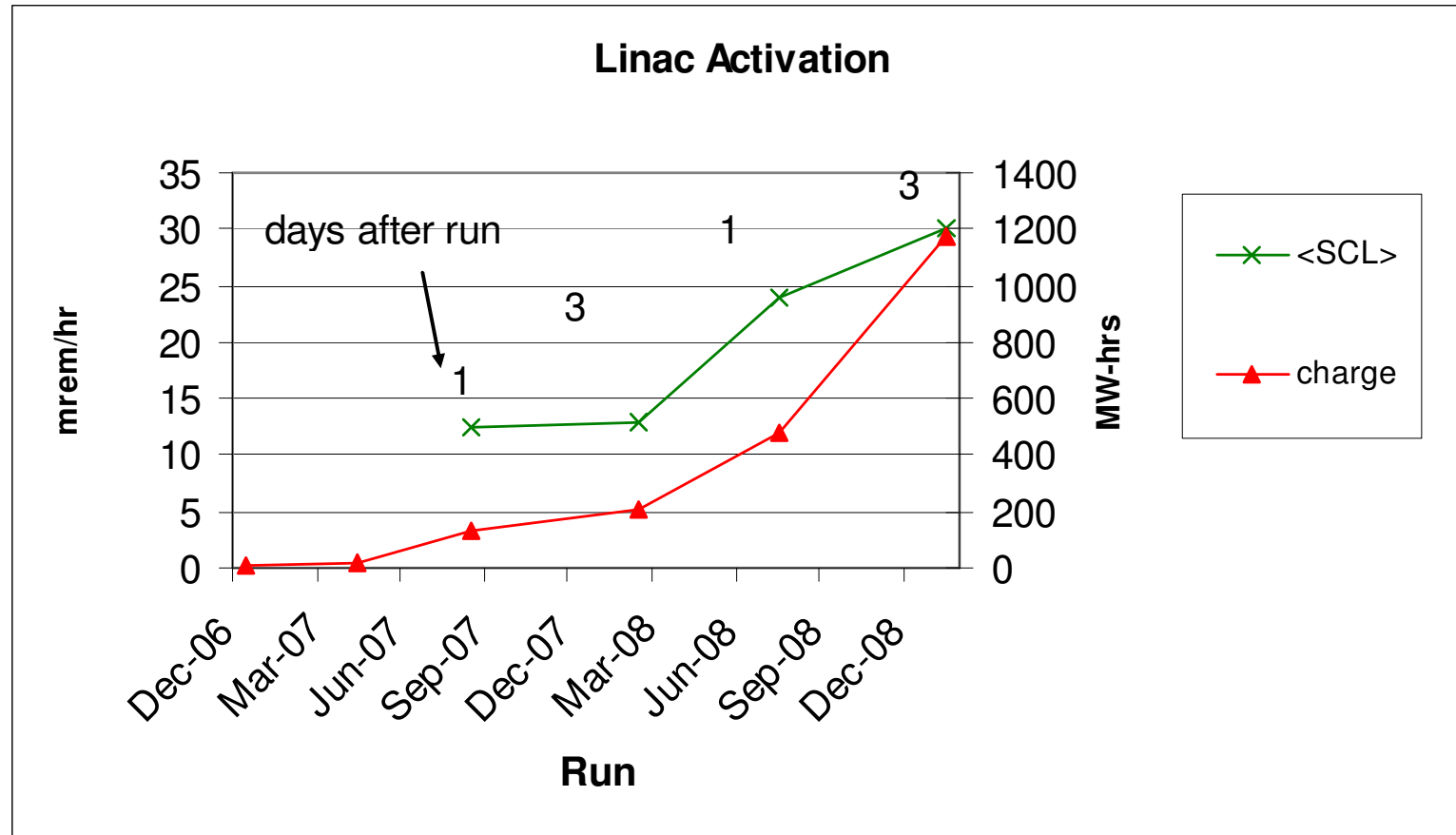
SCL Beam Loss

$$\text{Beam Loss} = \int \frac{\text{beam loss signal}}{\text{beam power on target}} dt \quad \text{over 3 week run}$$

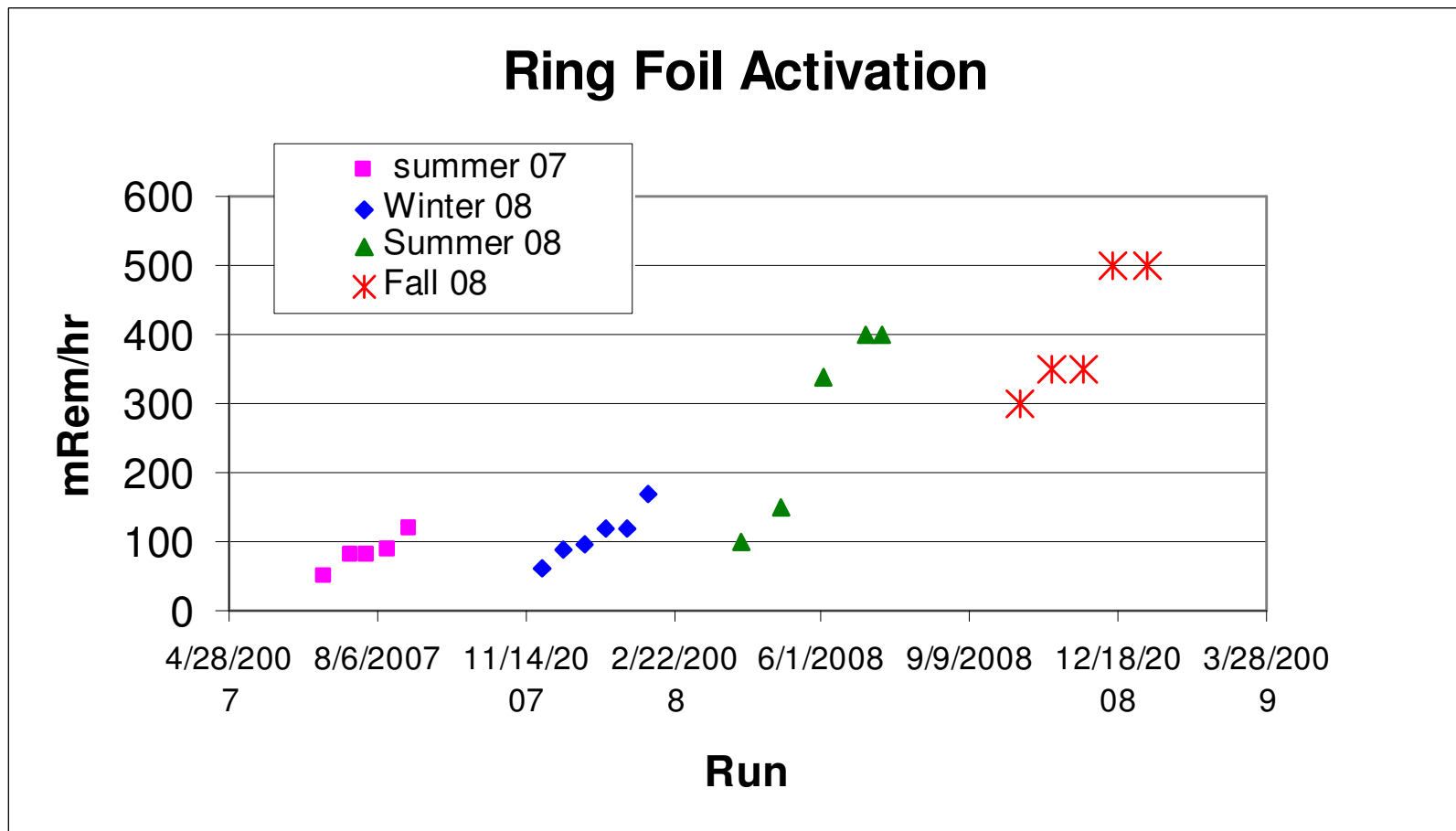


- Loss pattern is rock-solid
- Different longitudinal phase laws, transverse lattices, ...

SCL Residual Activation – End of Run Cycles

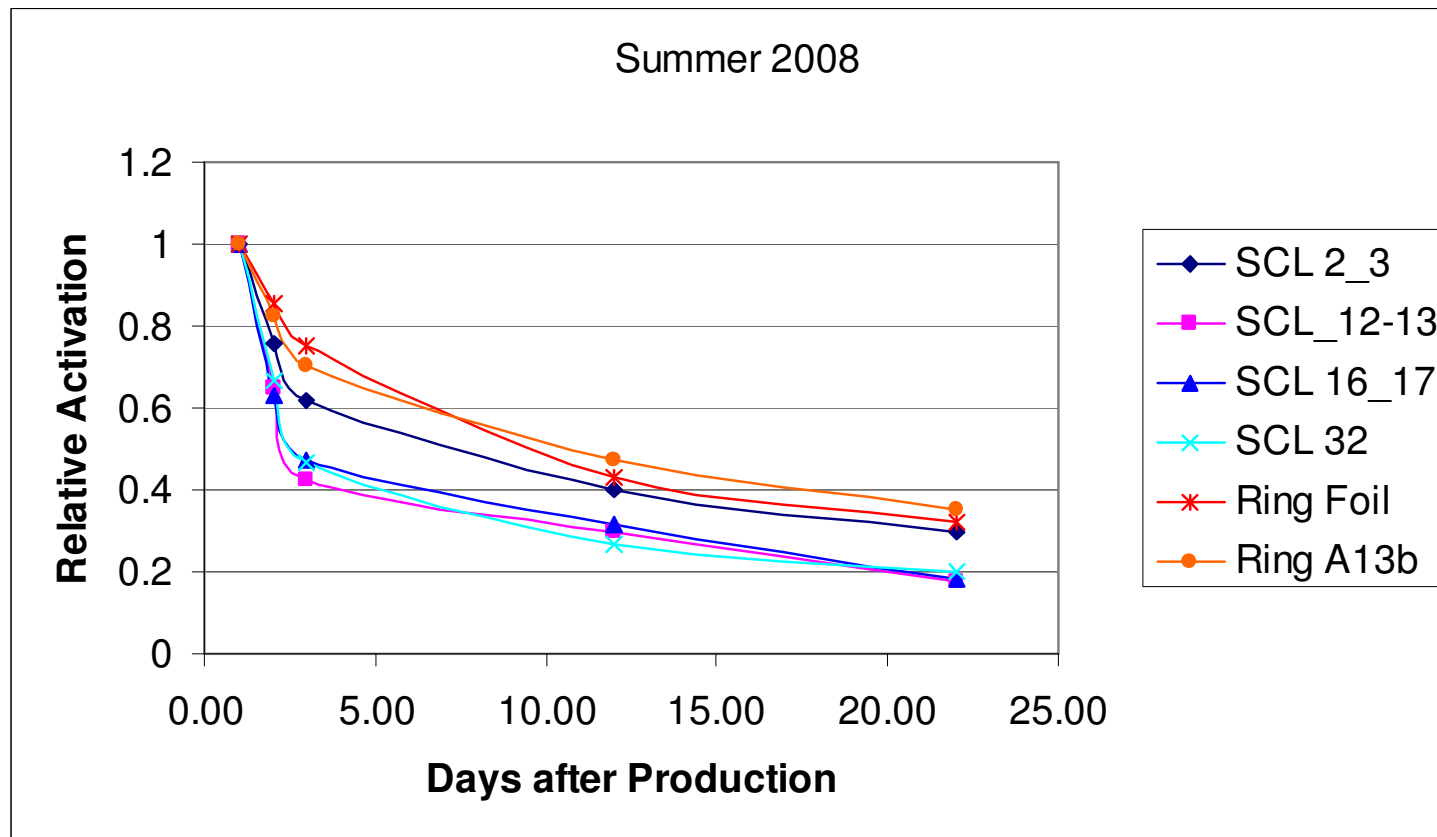


- Activation is not increasing proportional to the amount of beam transmitted
- SCL activation = average of all the warm section hot-spot readings



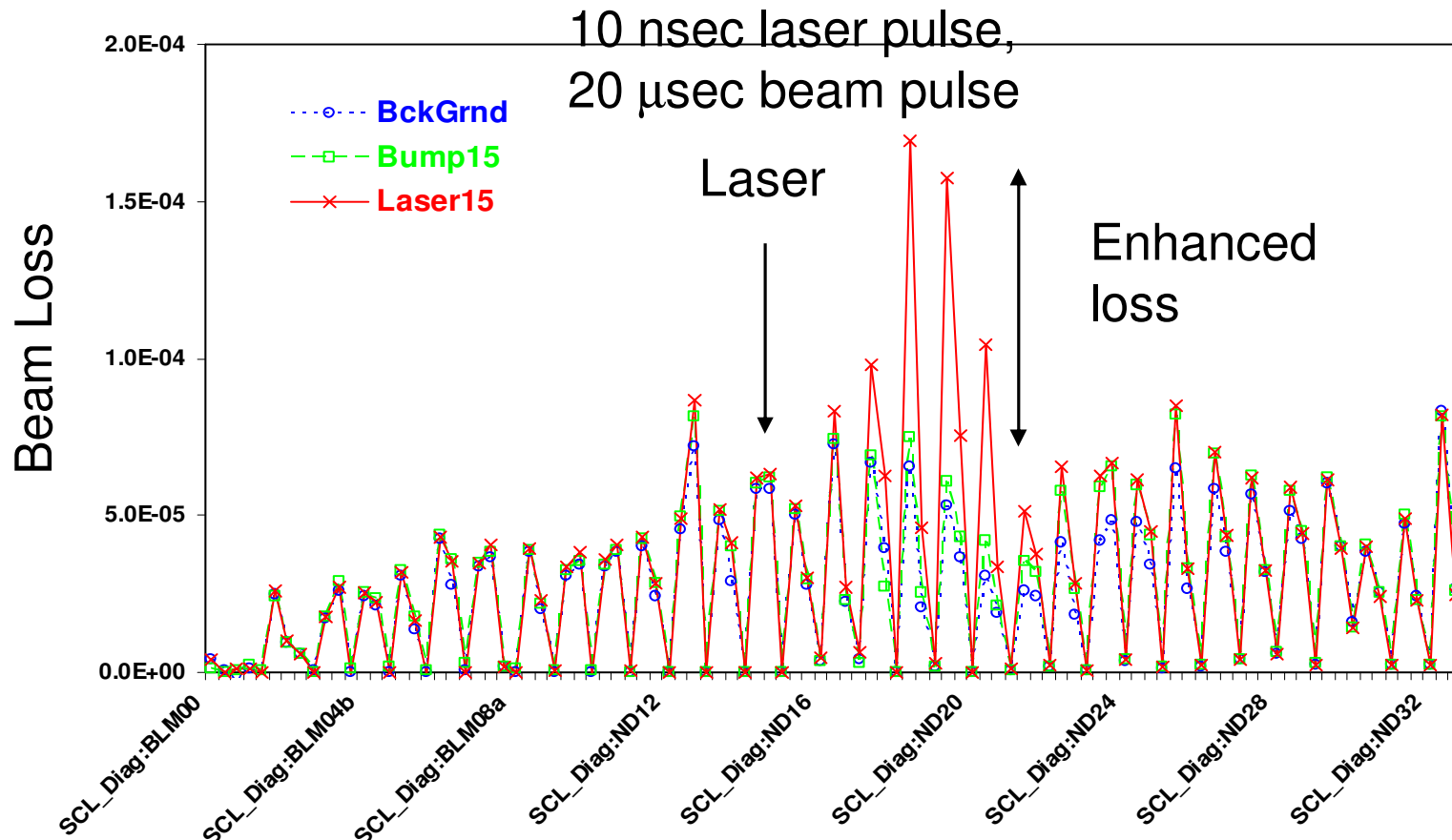
- SCL residual activation builds up quickly during a run cycle
- Contrast to Ring activation buildup, which is more steady

SCL Residual Activation has a Faster Initial Decay



- Suggests the presence of a short-lived “contaminant”
- We are planning additional gamma-spec measurements to identify material compositions
- In any case there is beam loss throughout the SCL, which is clearly measureable

SCL Beam Loss Magnitude

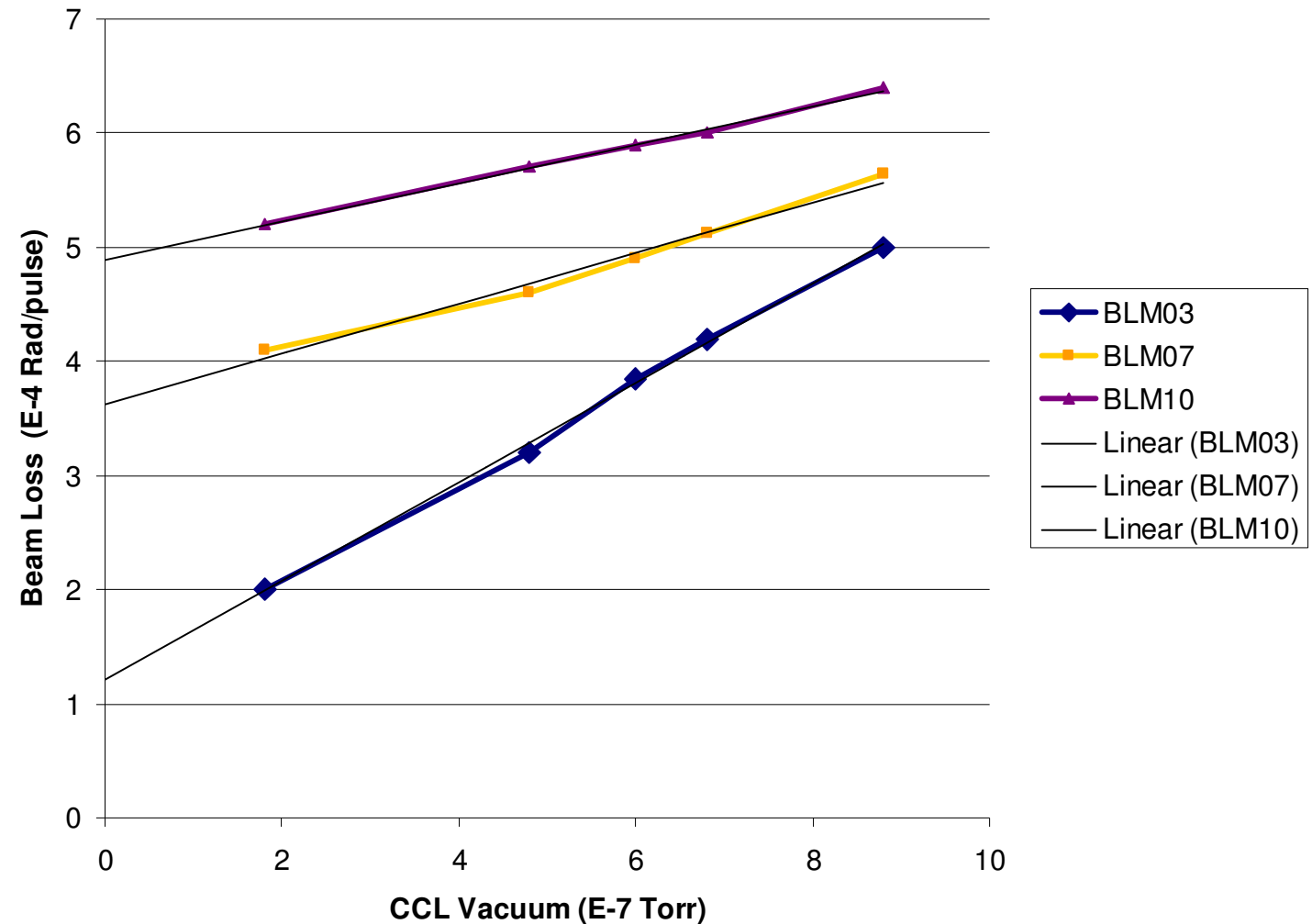
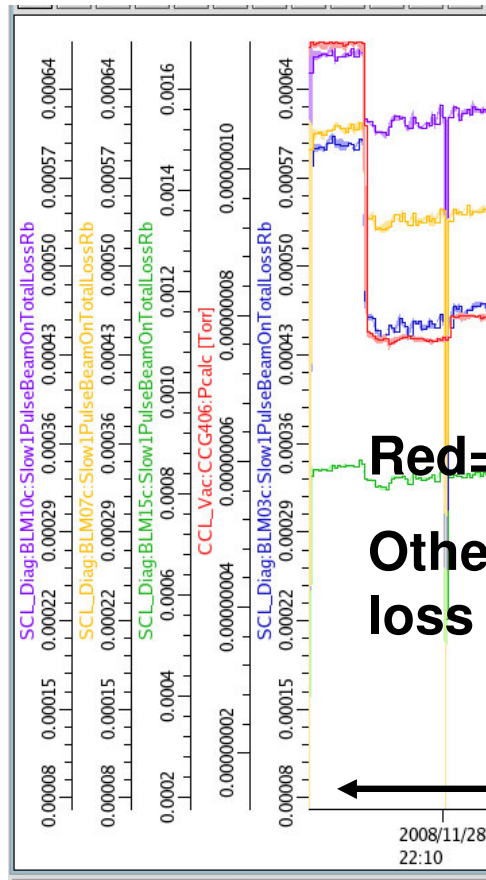


Single electron laser stripping is used for profile measurements in the SCL

- Using this to calibrate the BLM, $< 5 \times 10^{-6}$ beam lost at the highest loss point in the SCL during production
- Consistent with previous estimates from controlled loss spills, $\sim 2 \times 10^{-6}$ per warm section (\pm factors of 2-4)
- Activation of < 100 mrem/hr @ 1 ft after 12 hrs, scales with $< \sim 1$ W/m or $< 2 \times 10^{-6}$ beam loss/warm section

28 • Beam loss is a small fraction of the beam ($< 10^{-5}$) per warm section

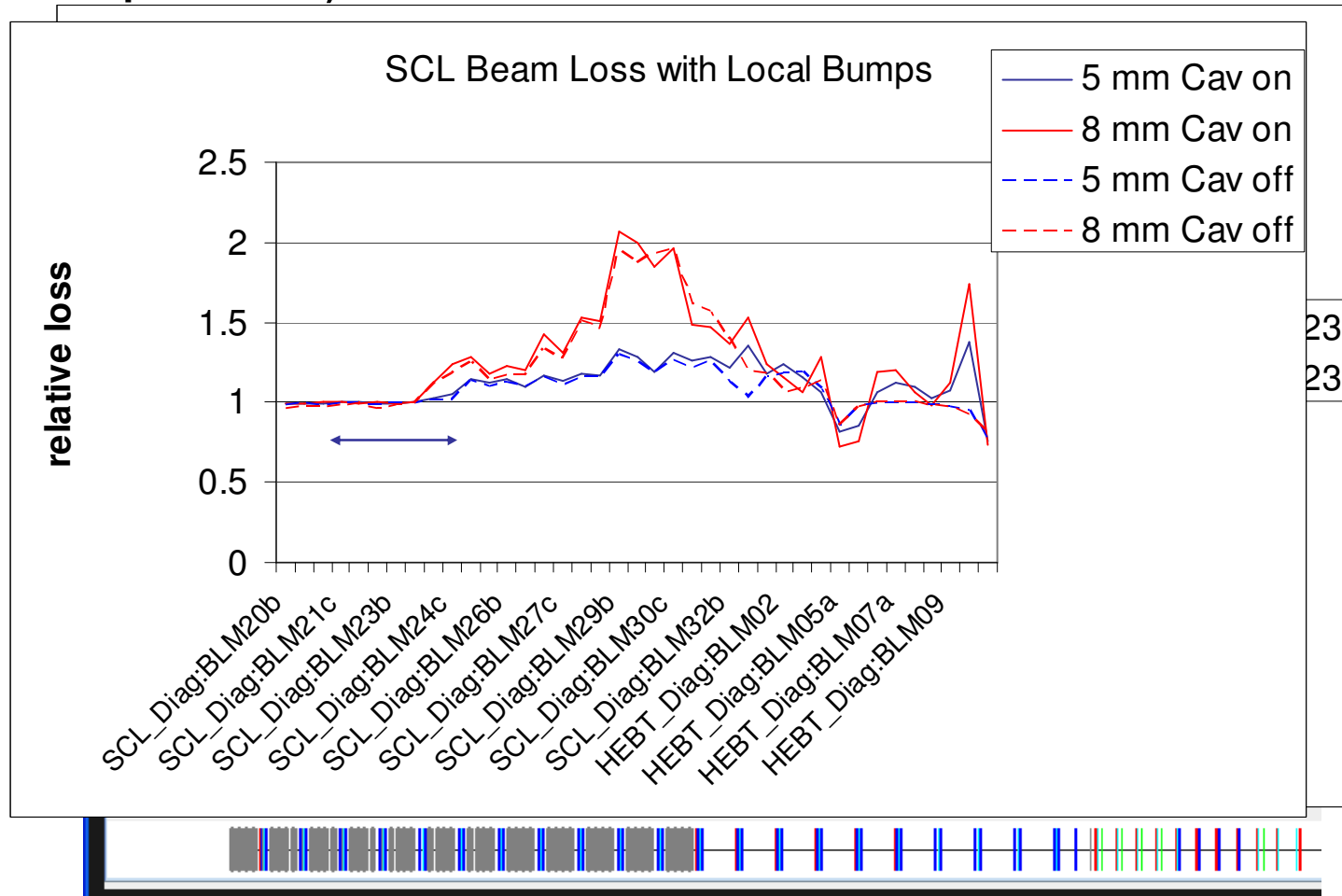
Upstream SCL Beam Loss Influenced by CCL Gas Stripping



- SCL Beam loss tracks CCL4 vacuum
- Upstream SCL losses strongly influenced by gas stripping
- From SCL10 downstream, relatively weak effect

SCL Beam Loss with Local Bump

- Bump (beam displacement) is local between sections 22-25



- Possible causes of enhanced loss

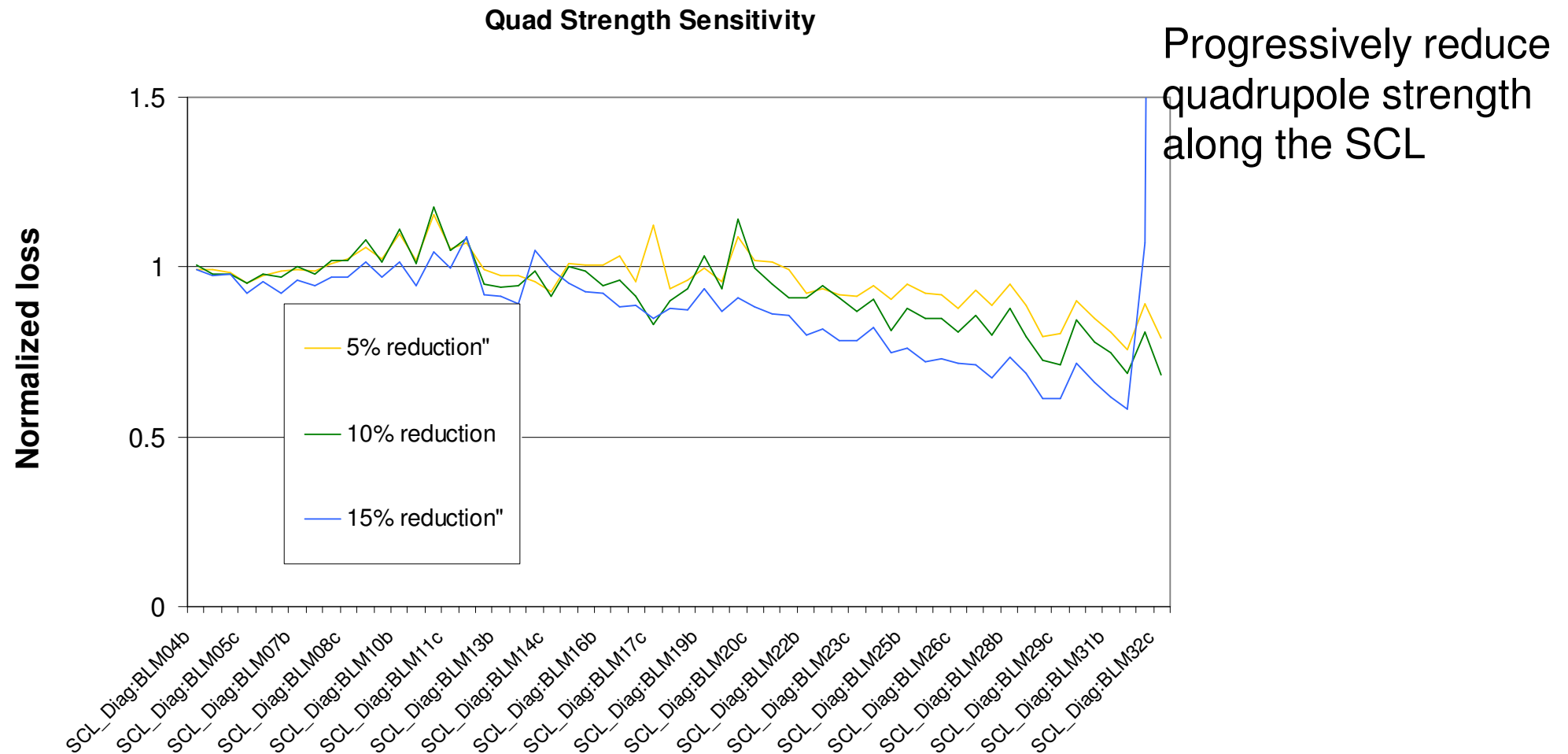
— ~~RF~~

— ~~Magnetic stripping~~

— Off energy beam

— Higher order magnet multi-poles (Y. Zhang's talk)

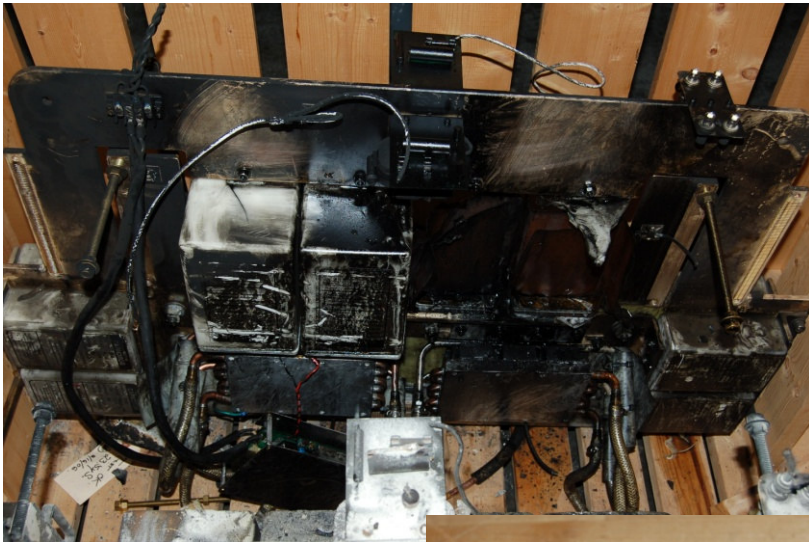
SCL Beam Loss with Reduced Quad Strength



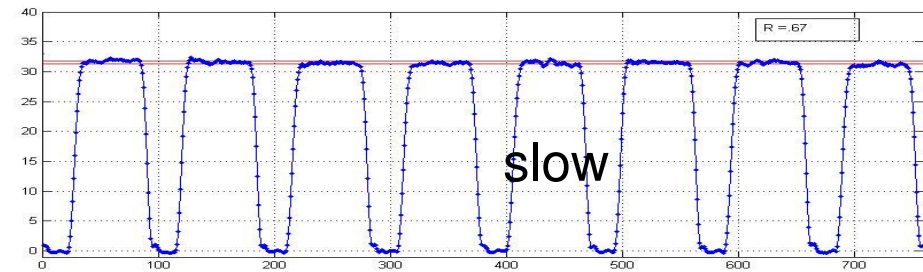
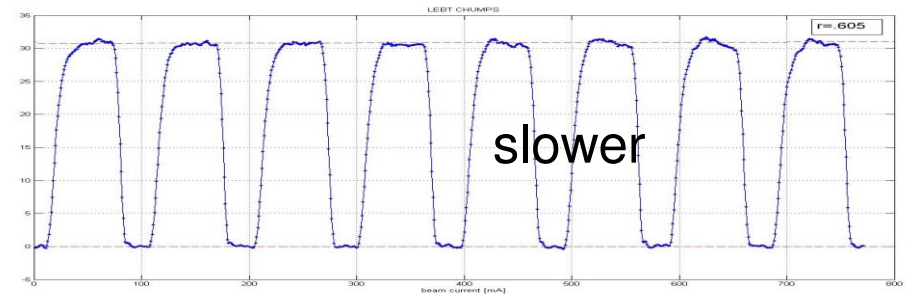
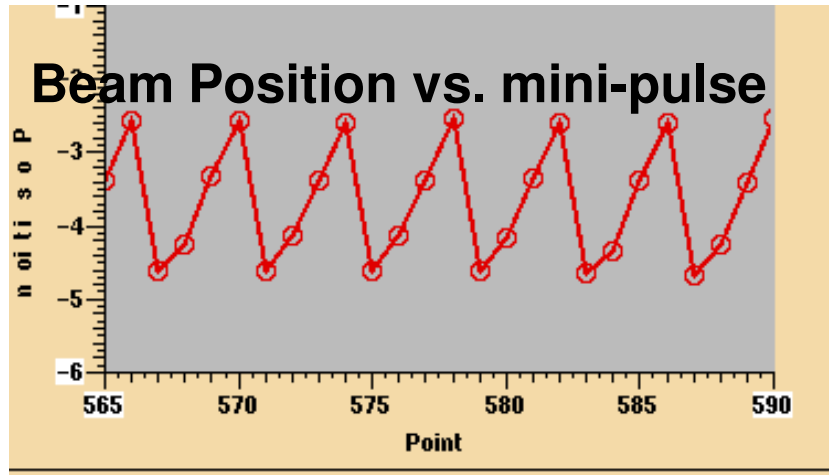
- Clear reduction in downstream beam loss
- Better transmission of off-energy beam?
- Lower effect of higher order magnet multipoles

Equipment Robustness / Reliability

- High Voltage Convertor Modulator (HVCM) component lifetimes
 - Creates the DC 60 Hz pulse forms using solid state technology
- Component lifetimes
 - New technology, minimal experience base



Chopper Issues



- Design is for 2 stage chopping
 - LEBT (slow) + MEBT (fast)
- MEBT structure + power supplies had issues
 - First used in summer 2008
- LEBT chopper electronics sensitive to sparks
 - Protection resistors added which slowed chopper even more

Summary

- **SNS: 6-7 year construction project**
- **After ~2 years of operation, ~ 700 kW beam power, 80% availability**
- **Some growing pains**
 - Implementations of complicated/new technologies – expect surprises
 - We have low levels of beam loss where we did not expect it, not loss limited (yet)
- **Gained some experience with the technologies and integrating issues of building, installing, commissioning and operating a high power linac.**

Summary (II)

- ESS is considering construction, commissioning and operation of a high power linac at a “green-field” site

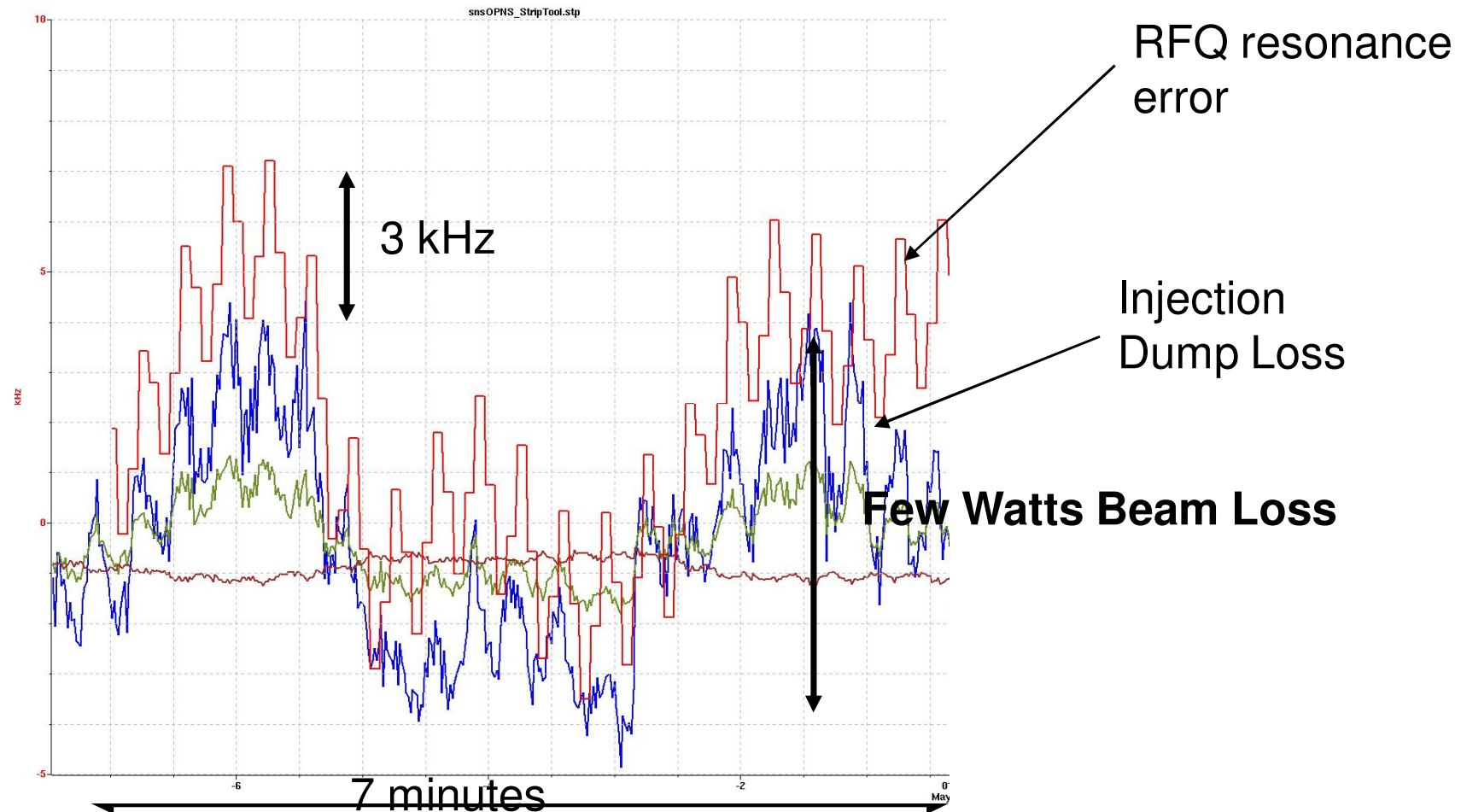


SNS: March 2000

It is possible

Hard to predict everything

Ring Injection Loss correlated with RFQ resonance error



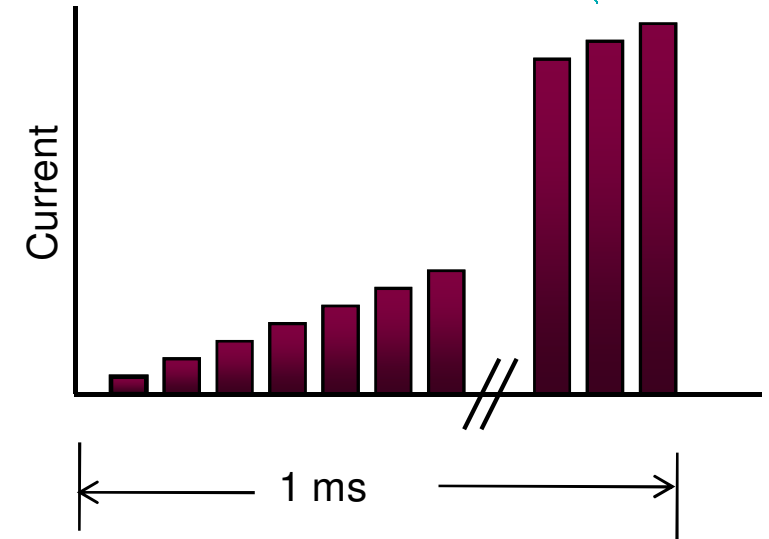
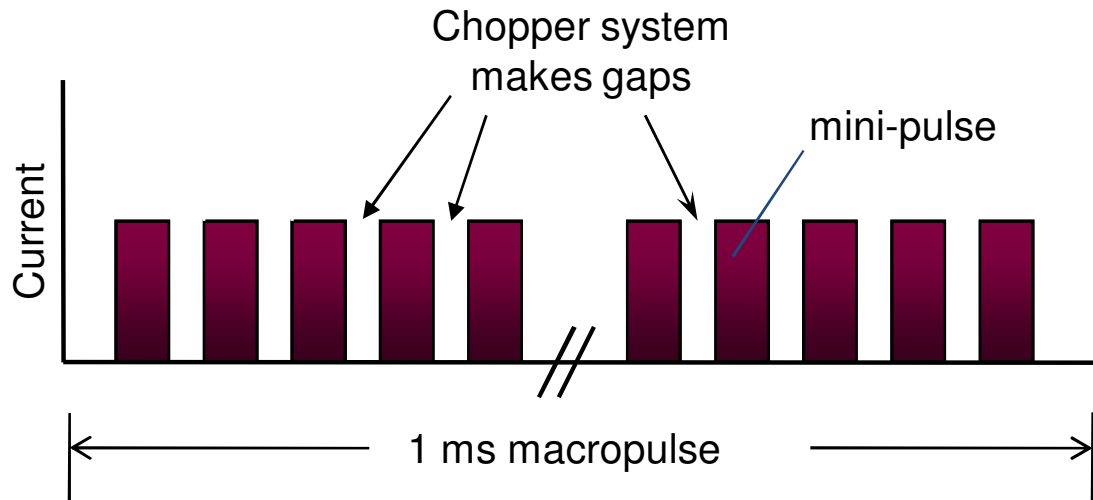
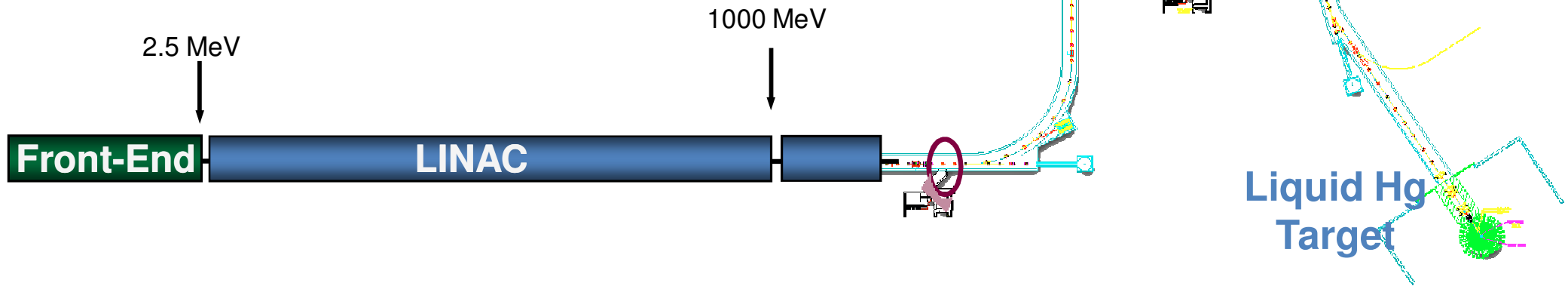
- Expect the unexpected

SNS Accelerator Complex

Front-End:
Produce a 1-msec
long, chopped,
H- beam

**1 GeV
LINAC**

Accumulator Ring:
Compress 1 msec
long pulse to 700
nsec



SNS Performance Relative to Design

	Design	Best Ever	Routine Operation
Kinetic Energy [GeV]	1.0	1.01	0.87
Beam Power [MW]	1.4	0.69	0.69
Linac Beam Duty Factor [%]	6%	3.6	3.6
Modulator/RF Duty Factor [%]	8%	5.4	5.4
Peak Linac Current [mA]	38	40	38
Average Linac Current [mA]	1.6	0.8	0.8
Linac pulse length [msec]	1.0	1.0	0.6
Repetition Rate [Hz]	60	60	60
SRF Cavities	81	76	76
Ring Accumulation Turns	1060	1020	620
Peak Ring Current [A]	25	22	13
Ring Bunch Intensity	1.5×10^{14}	1.3×10^{14}	8.1×10^{13}
Ring Space Charge Tune Spread	0.15	0.18	0.11